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(Statement A)

Monitoring Initiation and Growth of Crack in a Particulate Composite Material Using Nondestructive Testing Techniques

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An important engineering problem in structural design is evaluating structural integrity and reliability. It is well known that structural strength may be degraded during its design life due to mechanical or chemical aging, or a combination of these two aging mechanisms. Depending on the structural design, material type, service loading, and environmental condition, the cause and degree of strength degradation due to the different aging mechanisms differs. One of the common causes of strength degradation is the result of crack development in the structure.

In recent years, a considerable amount of work has been done in studying damage characteristics in highly filled polymeric materials, using nondestructive testing techniques (1-3). The importance of these studies stems from the fact that damage can significantly affect the constitutive and the crack growth behavior in these materials. Experimental findings reveal that damage, expressed in terms of the attenuation of the acoustic energy, increases with increasing strain rate and the critical damage is relatively insensitive to the strain rate. They also reveal that the damage state correlates well with the constitutive behavior of the material. In addition, for pre-cracked specimens, the damage state near the tip of a stationary crack is dependent on the loading history.

In this study, the damage field near the crack tip in an edge-cracked sheet specimen subjected to a constant strain rate of 0.125 min^{-1} was investigated

using the real-time x-ray technique. The specimen was made of the same particulate composite material as used in the ultrasonic tests. The specimen was 20.32 cm long, 5.08 cm wide, and 0.508 cm thick. Prior to testing, a 23 mm crack was cut at the edge of the specimen with a razor blade. During the test, Lockheed-Martin Research Laboratory's high-energy real-time x-ray system (HERTS) was used to investigate the characteristics of the damage field near the crack tip. During the test, the specimen ^{this type of} ~~was~~ placed between the x-ray radiation source and the x-ray camera. The x-ray image exits from the specimen and strikes the screen that is in front of the x-ray camera. The screen converts the x-ray image into a light image. This image is reflected into a low-light-level television camera by a mirror placed at 45° to the beam in the back of the camera. This isocon TV camera then converts the light image into an electronic signal that can be routed into the main monitor and into the video tape recorder. A detailed description of the HERTS system can be found in Reference 4. The recorded x-ray data were processed to create a visual indication of the energy absorbed in the material. A region of high absorption (i.e., a low damage area) ^{was} ~~will be~~ shown as a dark area, whereas a region of low absorption ^{i.e.,} ~~will produce~~ a light or white area, with 254 shades of gray in between. Also, the x-ray image at a given applied strain level ^{was} ~~can be~~ plotted in the form of iso-intensity contours of the transmitted x-ray energy I_x to enhance the resolution of the damaged field.

Figure 1 shows the contours of transmitted x-ray energy I_x near the tip of a propagating crack under the constant strain rate condition. In this figure, a small number indicates that the intensity of the transmitted x-ray energy is high or that the damage is high. These contour plots show the details of the size and shape of the damage zone as well as the damage intensity inside the damage zone.

As seen in Figure 1, the damage gradient near the crack tip is very steep. The region that has a steep damage gradient is restricted to a very small area in the immediate neighborhood of the crack tip. When the applied strain level is low, the damage intensity outside the steep damage gradient area is negligible. As the applied strain level is increased, the damage gradient is decreased and the size of the highly damaged region is increased as shown in Figure 2.

Experimental data indicated that at 13% applied strain level, a crack was developed near the center of the specimen (Fig. 2). As the specimen ~~was~~ ^{continued to stretch}, the two cracks propagated and, eventually, the right side tip of the developed crack and the tip of the edge crack connected. In this study, in addition to investigating the damage characteristics near the crack tip, the change of damage intensity as a function of the applied strain, prior to developing a crack, was also investigated. Experimental findings reveal that the damage rate is relatively small during the early stage of the crack development. However, the damage rate increases rapidly when the crack is about to be formed. This phenomenon is similar to that observed from a numerical analysis of the change in local normal strain prior to the formation of a crack. In the analysis, the Young's modulus of a finite element was reduced from 3.45 Mpa to 0.000007 Mpa with various values of modulus in between. When the modulus value is equal to 3.45 Mpa, the material is assumed to be in the undamaged state; whereas for the other values of the modulus, the material is assumed to be

damaged,

(add a space)
damage and a crack is formed when the value of the modulus is equal to 0.000007 Mpa. The results of the analysis, plotted with normal and shear strains as a function of the modulus, is shown in Fig. 4. In Fig. 4, we note that the normal and the shear strains increase gradually as the modulus is decreased from 3.45 Mpa to 0.14 Mpa and then, a significant increase in normal and shear strains occurs as the modulus is decreased from 0.0007 Mpa to 0.000007 Mpa. This indicates that, immediately before the formation of the crack, large normal and shear strains occur at the crack location.

In summary, the damage characteristics near the crack tip in a particulate composite material subjected to a constant strain rate were investigated using real-time x-ray techniques. Experimental findings reveal that damage zone size and the intensity of damage inside the damage zone increase with increasing time, and the damage rate increases rapidly prior to the formation of a crack. It also reveals that the real-time x-ray technique is a promising technique to monitor damage initiation and evolution processes in the particulate composite material.

References

- (1) Liu, C.T., "Effect of Load History on the Cumulative Damage in a Composite Solid Propellant," AIAA paper No. 86-1015.
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- (3) Tang, B., Liu, C.T. and Henneke, E.G., "Acoustic-Ultrasonic Technique Applied to the Assessment of Damage in a Particulate Composite," Journal of Spacecraft and Rockets, Vol. 32, No. 5, 1995.
- (4) Sklensky, A.F. and Buchanan, R.A., "Sensitivity of High-Energy Real-Time Radiography with Digital Integration," ASTM STP 716, 1980.

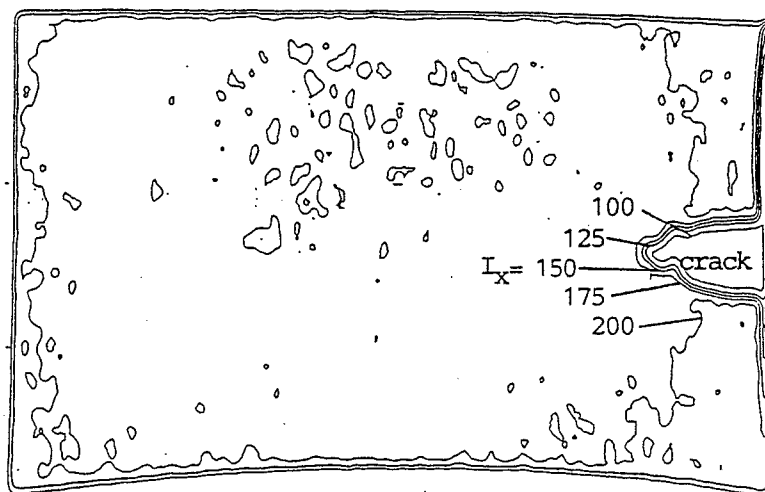


Fig.1 Iso-intensity contour plots of transmitted ray energy I_x (one crack).

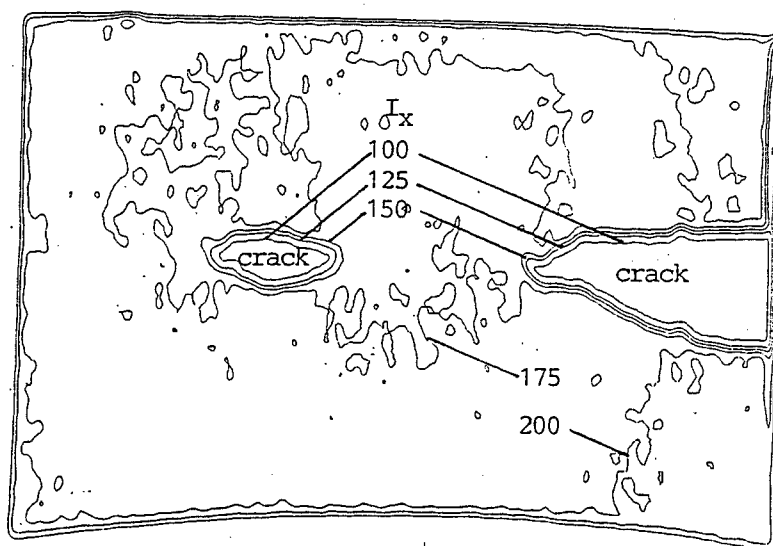


Fig.2 Iso-intensity contour plots of transmitted x-ray energy I_x (two cracks).

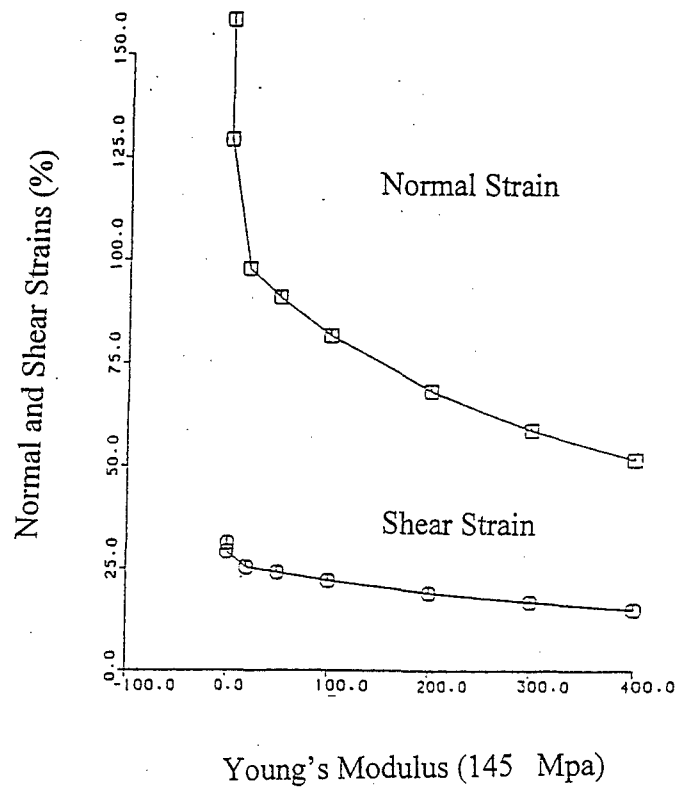


Fig.3 Normal and shear strains versus Young's modulus.